European Commission

LOW CARBON ENERGY OBSERVATORY

SOLAR THERMAL HEATING AND COOLING

Technology development report

Joint Research Centre

EUR 29915 EN

Contact information

Name: Johan CARLSSON
Address: European Commission, Joint Research Centre, Petten, The Netherlands
Email: johan.CARLSSON@ec.europa.eu

Name: Piero DE BONIS
Address: European Commission DG Research and Innovation, Brussels, Belgium
Email: Piero.DE-BONIS@ec.europa.eu

EU Science Hub
https://ec.europa.eu/jrc

JRC118301

EUR 29915 EN

PDF	ISBN 978-92-76-12539-6	ISSN 2600-0466 ISSN 1831-9424 (online collection)	doi:10.2760/706387
Print	ISBN 978-92-76-12538-9	ISSN 2600-0458 ISSN 1018-5593 (print collection)	doi:10.2760/315917

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: M. Jakubcionis, Solar Thermal Heating and Cooling Technology Development Report 2018, EUR 29915 EN, European Commission, Luxembourg, 2019, ISBN 978-92-76-12539-6, doi:10.2760/706387, JRC118301.

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

CAPEX	Capital expenditure
CST	Concentrated solar thermal
DHC	District heating and cooling
FP6	6^{th} Framework Programme
FP7	7^{th} Framework Programme
H2020	Horizon 2020 Programme
IEE	Intelligent Energy Europe
LCEO	Low Carbon Energy Observatory
NREAP	National Renewable Energy Action Plan
NZEB	Near zero energy building
OPEX	Operating expenditure
PV	Photo voltaic
PV-T	Hybrid solar photovoltaic thermal system
R&D	Research and Development
RES	Renewable energy sources
RHC	Renewable Heating and Cooling
SAH	Solar active house
SCOHYS	Solar compact hybrid system
SDH	Solar district heating
SHC	Solar Heating & Cooling
SHIP	Solar heat for industrial processes
TRL	Technology readiness level

ACKNOWLEDGEMENTS

The author would like to thank JRC colleagues who contributed to this report:

- The energy modelling work has been performed by the JRC-EU-TIMES team: Wouter Nijs, Pablo Ruiz Castello, Savvas Politis, Robert Houghton and Andreas Zucker.
- The author would especially like to thank Johan Carlsson, Nigel Taylor and Piero de Bonis who have reviewed the draft and helped greatly improving this report.

FOREWORD ON THE LOW CARBON ENERGY OBSERVATORY

The LCEO is an internal European Commission Administrative Arrangement being executed by the Joint Research Centre for Directorate General Research and Innovation. It aims to provide top-class data, analysis and intelligence on developments in low carbon energy supply technologies. Its reports give a neutral assessment on the state of the art, identification of development trends and market barriers, as well as best practices regarding use private and public funds and policy measures. The LCEO started in April 2015 and runs to 2020.

Which technologies are covered?

- Wind energy
- Photovoltaics
- Solar thermal electricity
- Solar thermal heating and cooling
- Ocean energy
- Geothermal energy
- Hydropower
- Heat and power from biomass
- Carbon capture, utilisation and storage
- Sustainable advanced biofuels
- Battery storage
- Advanced alternative fuels

How is the analysis done?

JRC experts use a broad range of sources to ensure a robust analysis. This includes data and results from EU-funded projects, from selected international, national and regional projects and from patents filings. External experts may also be contacted on specific topics. The project also uses the JRC-EU-TIMES energy system model to explore the impact of technology and market developments on future scenarios up to 2050.

What are the main outputs?

The project produces the following report series:

- Technology Development Reports for each technology sector
- Technology Market Reports for each technology sector
- Future and Emerging Technology Reports (as well as the FET Database).

How to access the reports

Commission staff can access all the internal LCEO reports on the Connected LCEO page. Public reports are available from the Publications Office, the EU Science Hub and the SETIS website.

1 INTRODUCTION

1.1 Overview of methodology and data sources used

The purpose of this report is to provide an assessment of the state of the art of solar heating and cooling technologies, to identify the development need and barriers and to define areas for further R&D in order to meet announced deployment targets and EU policy goals.

Solar heating and cooling is a very broad definition and encompasses many different technologies and uses. Some components of solar heating and cooling systems are inherently unique, such as solar collectors which gather solar irradiation and transform it into heat. Solar heating and cooling systems share other components, such as heat accumulators, heat exchangers or hydraulic circuits and electronics with other heating and cooling technologies. The analysis in this report is primarily focussed on developments in solar collector technologies but other relevant components are discussed and analysed as well.

Due to the natural variations in solar irradiation solar heating and cooling is often integrated with other heating and cooling systems to make optimal use of its contribution. R&D on hybrid systems (combining solar heating and cooling with other technologies) is also analysed in this report.

A literature review was carried out to assess the state of the art of solar heating and cooling technologies. This was based on reports such as: Solar Thermal Markets in Europe [ESTIF, 2016], Solar Heating and Cooling Technology Roadmap [Ivancic et al, 2014], Strategic Research Priorities for Solar Thermal technology [Stryi-Hipp et al, 2012], Review of Solar Thermal Technologies [Thirugnanasambandam M. et al, 2010], Solar Water Heaters [IRENA, 2015], as well as other relevant reports.

For the solar thermal technologies in the residential building sector, annual reports and roadmaps from industrial organisations and European and other international projects have been assessed for technology trends and market data.

In order to understand technology needs and barriers, an analysis of EU co-funded projects as well as national, intra-EU and international funds available has been carried out.

This report uses a range of different data sources, including scientific reports, specialised literature and expert judgement.

The analysis focused on all instances of solar heating and cooling use, such as low temperature technology mostly used in buildings or the use in industrial processes.

Regarding the status of the solar thermal market in Europe, annual data are available from national energy agencies, the solar thermal industry and several organizations, such as IEA [IEA, 2012] and EurObserv'ER [EUObserv'ER, 2017]. The ESTIF association provides annual information on market developments and trends [ESTIF, 2016].

Available data reflects the capacity of installed installations and not directly the energy produced or consumed from solar thermal systems. The available data over the past years gives a clear trend that can be linked to the 2020 targets set by the Member States [European Parliament, 2009; European Commission, 2017].

CORDIS[1] and other sources provided data on the solar thermal related H2020 projects. European funded projects under the IEE, FP6 and FP7 programmes were addressed in the previous version of the LCEO Solar Thermal Heating and Cooling Technology Development Report [Bloem, 2016]. Since the present report focusses on H2020, it only briefly discusses these earlier projects.

1.2 Technology and market overview

Heating and cooling of our buildings and industry accounts for half of the EU's energy consumption. In EU households, heating and hot water alone account for 79 % of total final energy use. Cooling currently accounts for a small share of total final energy use. Space cooling counts for 2 % and process cooling for 3 % of EU heating and cooling end uses (European Commission, 2016).

84 % of heating and cooling in EU is still generated from fossil fuels while only 16 % from renewable energy. In order to fulfil the EU's climate energy goals, the sector must sharply reduce its energy consumption and cut its use of fossil fuels (European Commission, 2016).

Solar heating has been used for heating buildings and for industrial processes (such as drying of various products) for centuries. With the developments in sanitation systems and invention of central heating systems solar assisted heating began to be used on a broader scale. Currently, gathering of solar irradiation by using of solar collectors and conversion of it into thermal energy is a well-known and established technology, albeit facing some significant challenges in a changing energy environment.

One of the main challenges is related to the natural daily variations in solar irradiation. The solution is to use heat storage. However, in order to have a consistent supply of heat, the storage must be large enough to account for periods with lowered solar irradiation intensity, such as rainy or cloudy days. Another important aspect is seasonal inconsistency of solar irradiation. Solar irradiation is significantly lower during the winter months, when space heating demand is at its peak and reaches its peak during the summer months when space heating demand is at its lowest. However, this makes solar thermal particularly suitable to provide space cooling.

Other challenges are related to increased competition with other renewable energy sources. In particular, this applies to solar PV technology with which solar heating systems share many similarities in the layout of the components. As both solar PV and solar thermal use solar collectors (although of different operating principles) they compete for the available placement space as well.

Solar thermal encompasses a number of different technological solutions and applications.

Solar heating systems can be of a passive or an active mode of operation. An example of the passive system would be dark painted south facing external and internal surfaces of the buildings intended to gather and accumulate solar irradiation. Although a well-known and used means of providing supplementary heating of the buildings, it is rarely analysed or

[1] The Community Research and Development Information Service (CORDIS) is the European Commission's primary source of results from the projects funded by the EU's framework programmes for research and innovation (FP1 to Horizon 2020) – see https://cordis.europa.eu/en

quantified methodically on a large scale. Although a significant contributor to lowering heating demand in the buildings, passive solar heating was not analysed in this report.

Instead, this report is focused on active solar heating and cooling, i.e. covering heating and hot water preparation as well as air conditioning needs by gathering solar energy and transferring it inside of the buildings by using a liquid or gaseous heat transfer medium, such as air, water or glycol. Active solar heating is used for different applications, shortly discussed below.

Solar sanitary hot water preparation. This is the primary solar thermal application since the temperature level needed is moderate (45 °C to 60 °C) and SHW is needed whole year round, albeit additional heat sources, e.g. gas boiler, are needed during the cold season. The residential segment accounted for 63 % of the total installed solar collector capacity at the end of 2014 [Sawin et al, 2016].

Space heating. Solar space heating is another use of low temperature solar thermal systems. Solar space heating has an important development potential in Southern Europe. A recent and gathering momentum trend in some countries (especially Denmark) is to use solar energy as a heat source of district heating networks.

Industrial solar heating applications. Here solar energy is used to provide heat in industry and agriculture. Although solar thermal technology could cover significant share of industrial heat needs, currently the deployment of solar thermal technologies in industry is just a fraction of that in the residential sector.

Solar cooling. This application is widely regarded as promising in regions with high radiation and significant cooling demand. Solar cooling currently has only a very small presence in the market [Stryi-Hipp et al, 2012].

The cumulated solar thermal capacity in operation in the world by the end of 2016 was 456 GWth (652 million m²). Solar thermal capacity increased by 4.6 % in comparison with 2015. Compared to the year 2000 the installed capacity grew by a factor of 7.4. The corresponding annual solar thermal energy yield in 2016 was 375 TWh, which correlates to the savings of 40.3 million tons of oil and 130 million tons of CO_2 [Weiss et al, 2017]. The largest share of global solar thermal capacity is installed in China (71 %) and EU (8 %).

In 2016 2.7 million m² of solar collectors were installed in EU compared to 4.6 million m² installed in 2008 [EurOBserv'ER, 2017]. Almost 30 % of the newly installed collector area in the EU in 2015 was in Germany. The second largest addition of solar collectors occurred in Poland [EurOBserv'ER, 2017].

Total production of solar thermal energy in EU-28 countries in 2015 was 49.5 TWh [Eurostat, 2016]. The share of solar thermal in the total production of renewable energies in EU-28 in 2015 was 2.1 %, a significant increase from a 0.6 % share in 2004. More than a half of solar thermal energy in 2015 was produced in Spain (28.8 TWh). However, the largest part of solar thermal energy produced in Spain was used to generate electricity. Thus the solar thermal energy used directly for heating and cooling purposes (disregarding solar thermal used as a transformation input) in EU in 2015 was 23.6 TWh.

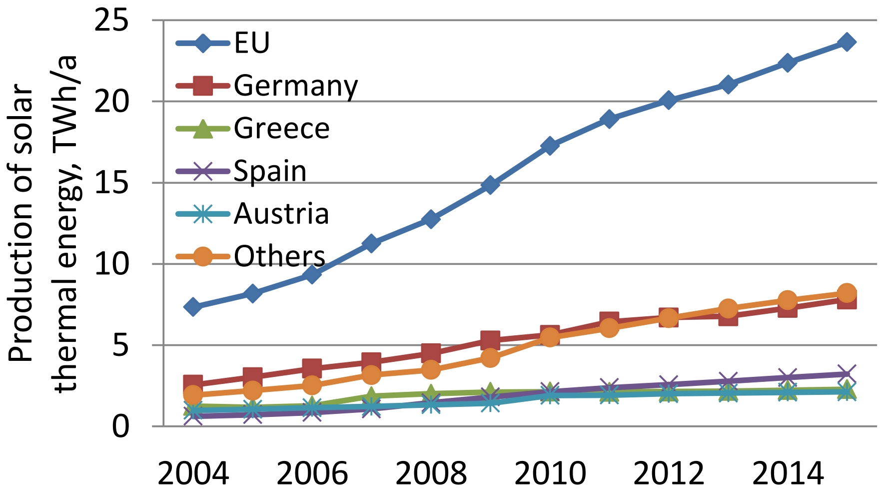

Figure 1 Production of solar thermal energy in EU-28 countries [Eurostat, 2016]

However, in recent years the solar thermal sector is facing significant difficulties, both globally and in EU. In 2015 40.2 GWth of solar collectors were installed worldwide, which is 14 % less compared to 2014 [Weiss et al, 2017], [Sawin et al, 2016]. Since 2009 the European Union's solar thermal market has been contracting by an annual average of 6.9 %.

German flat plate collector manufacturers dominate the top-20 ranking of the world's largest manufacturers, among them Bosch, Viessmann, Vaillant, Thermosolar and Wolf. China is ranked second with four manufacturers, i.e. Five star, Prosunpro, BTE solar, and Sunrain. Turkey is placed third with three producers. The three largest vacuum tube collector manufacturers are all based in China [Sawin et al, 2016].

Despite these difficulties, solar thermal energy together with other RES can be a major source of heating and cooling in Europe. However, in order to unlock its potential and to give the solar thermal industry a boost, directed and coordinated research and innovation activities are urgently needed.

In terms of EU priorities for R&I, the stakeholders in SET-Plan Integrated Roadmap [SET-Plan, 2014] identified in detail a number of issues to be tackled:

- reduction of solar heat costs by highly integrated compact hybrid heating systems,
- increase the solar fraction per building by staying at the same heat costs,
- reduce solar heat costs for industrial processes,
- optimize the energetic design of the nearly zero energy buildings with high solar fraction.

These were accompanied by ambitious strategic targets requiring a facilitating research and innovation framework.

In 2015 the SET-Plan was reorganised under the overarching Energy Union policy and solar thermal is considered an integral part of SET-Plan Action 5 on the development of new materials and technologies for energy efficiency solutions for buildings. These are specific research objectives for solar collectors, although thermal storage systems are a priority area.

2 TECHNOLOGY STATE OF THE ART

2.1 Solar collectors

The collector is the most important component of the solar thermal system. In addition, it comprises a collector loop and a storage system. The collector loop and storage system can be configured in a passive as well as active way.

Water-based flat plate collectors and evacuated tube collectors are the most commonly used today. They were subject of significant development in the last few decades and can be very efficient due to the use of selective coated absorbers and highly transmissive glass. Other efficiency improvement measures, for instance anti-reflective coating, are used as well. These collectors work very effectively for low to medium temperature solar heating and cooling applications.

Although the basic configuration of solar collectors and choice of materials for their manufacture is well established, recent research has provided a number of alternative solutions. For instance, the FP7 project SCOOP [Bloom, 2016] investigated possibilities to use polymer materials for solar collector manufacture. According to the final report of the project, collector- and system designs based on the use of polymeric materials were developed, tested and made ready to enter the market.

Concerning efficiency of solar collectors, the IEA Solar Heating & Cooling Programme, together with ESTIF and other major solar thermal trade associations agreed to publish statistics in kWth and to use a factor of 0.7 kW_{th}/ m^2 to convert the collector area (glazed flat plate and vacuum tube) area into kW_{th} [Nielsen, 2011].

2.1.1 Flat plate collectors

This type of solar collector is made of a metal box having dark absorber plate on the bottom with a glass or plastic cover (called glazing) on top. The cut-out view of a typical flat plate solar collector is presented in Figure 2. Water or another liquid flows through the pipes attached to the absorber plate. The absorber plate and pipes are covered with selective coatings, which are designed to absorb and retain heat.

The transparent cover is intended to reduce heat losses and to protect the absorber plate and pipes from adverse weather conditions. Cheaper flat plate collectors are made without glazing. This reduces their price but increases heat losses, especially under windy and cool weather conditions. Unglazed flat-plate collectors are very efficient at low output temperatures (up to 30 °C) but suffer high heat losses and have low efficiency when output temperature increases. Thus they are mainly used for heating of water in swimming pools.

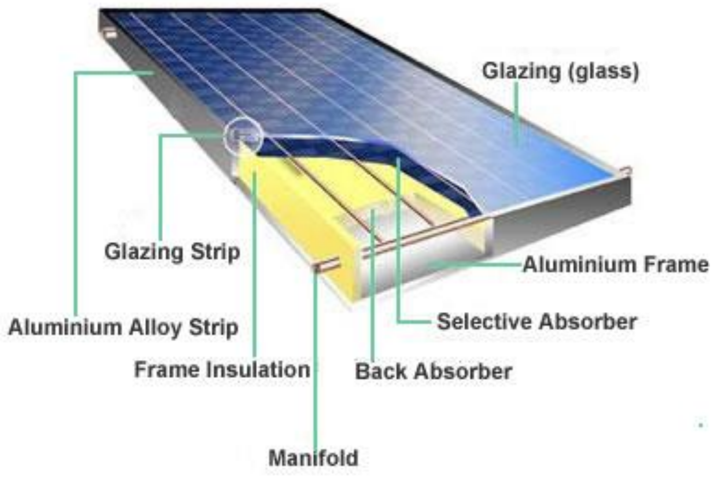

Figure 2. Cut-out view of a flat plat solar collector (Source: Igneus Ltd.)

Flat plate solar collectors are the most common on the EU market and most popular choice for domestic hot water production. 91 % of newly installed solar thermal collectors in EU in 2015 were of flat plate type [ESTIF, 2016].

The most critical issue affecting the performance of the collector is the coupling of the heating liquid circulation tubes with the absorber which is addressed using different manufacturing technologies [Treberspurg et al, 2011].

Flat plate collectors can be installed using a simple supporting structure on the roof of the building or can be integrated into a sloped roof. They can also be installed on the ground outside of the building if free space is available. Collectors usually are stationary with their orientation selected to optimise different modes of operation (annual or warm season). Their efficiency can be improved by using tilting and rotating mechanisms although such solutions make them more expensive and generally are not used for small scale systems.

Flat plate collectors can be used to provide higher temperature (80-120 °C) hot water by using different modifications. These are intended to reduce thermal losses of the collector at the same time limiting their optical efficiency losses. This can be achieved, for instance, using multiple glazing with anti-reflective glass.

The currently used flat plate solar collectors are water based, i.e. a fluid flows through the collector thus ensuring heat transfer from the collector to a heat user. Solar air collectors have air circulating through them using an electric air fan. This type of collector is currently not very common in Europe due to many reasons. One of the main reasons is that solar air collector cannot be used directly for domestic hot water production which is currently the main application of solar heat [Treberspurg et al, 2011].

2.1.2 Evacuated tube collectors

Evacuated tube collectors are made of rows of parallel transparent glass tubes which are connected to a header pipe. A schematic view of a single tube is presented in Figure 3.

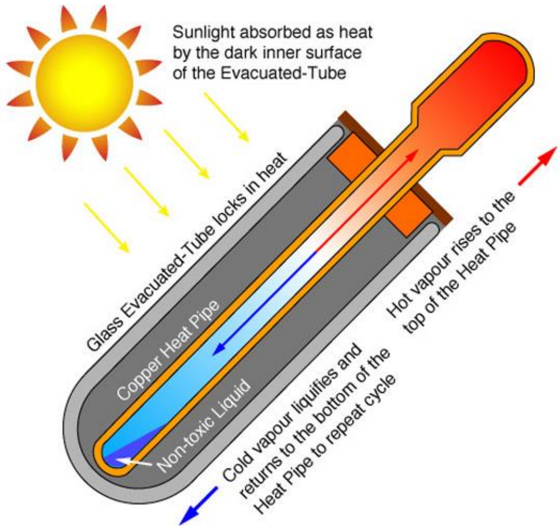

Figure 3. Diagram of an evacuated tube collector's tube (Source: Skyreach Solar - Scanpower Ltd.)

Figure 4. State of the art evacuated tube collector, using high temperature composites for the manifold. Source: Kingspan

Each tube has an outer glass tube and an inner tube. The inner tube has a selective coating with high solar heat absorption and low heat reflection properties. The air between the inner and outer tube is evacuated. This eliminates conductive and convective heat losses of the collector. Besides different geometrical configurations it has to be considered that the collector must always be mounted with a certain tilt angle in order to allow the condensed internal fluid of the heat pipe to return to the hot absorber [Treberspurg et al, 2011]. A view of a state-of the art evacuated tube solar collector is presented in Figure 4.

Evacuated tube collectors in Europe are less common, although they dominate the Chinese market. Approx. 88 % of solar collectors installed in 2015 in China were of this type. Among other reasons this might be explained by the fact that the largest evacuated tube manufacturers are based in China (Sawin et al, 2016).

2.1.3 Concentrating solar collectors

Although improved flat plate and evacuated solar collectors can be used in medium temperature applications, temperatures above 250 °C are achieved using concentrating collectors, similar to the ones used in solar thermal electricity systems. The most common technological solutions include parabolic trough, parabolic dish and power tower.

A parabolic trough has a curved parabola surface in two dimensions while remaining straight in the third dimension. The surface of the collector plates is lined with a polished metal mirror that reflects and focuses the sunlight onto the tube located along the focal line of the collector. This tube contains a fluid that is heated to a high temperature by the energy of the sunlight.

In a parabolic dish solar collector reflective mirrors are arranged on a parabolic surface. The mirrors reflect the sunlight and focus it to produce high temperate water or steam.

A power tower is a large tower surrounded by tracking mirrors which focus the sunlight on the receiver located at the top of the tower.

2.2 Hybrid solar photovoltaic thermal (PV-T) systems

Hybrid solar photovoltaic thermal (PV-T) panels combine two well-established renewable energy technologies, solar photovoltaics (PV) modules and solar thermal collectors, into one integrated system that removes heat from the PV modules thereby improving electrical efficiencies. Removed heat can then be used for heating and cooling purposes. The combination of these two technologies can substantially increase the total energy (electric and thermal) generation per m² [Treberspurg et al, 2011]. In some cases it is possible to generate the same amount of energy in 40 % less area (compared to a side-by-side installation of solar PV and solar thermal collectors) [Treberspurg et al, 2011].

In addition the percentage of solar irradiation converted into useable energy is potentially increased due to the different ranges of the solar spectrum gathered by solar PV and solar thermal collectors. [Ramos et al, 2017]. Solar PV cells operate in a wavelength range of 350-1200 nm (i.e. mainly visible light, UVA and the lower end of infrared). The solar energy of other wavelength can be collected in the form of heat and co-generation conversion can reach 80 % (IEA, 2011).

Domestic PV-T systems can be installed to contribute to hot water demand and/or low temperature space heating as well as supplying renewable electricity. Generally domestic scale PV-T systems are not able to generate sufficient heat all year round to cover all the heating requirements of a home and therefore need to be operated in conjunction with another heating technology. [Ramos et al, 2017].

PV modules and solar thermal collectors can be combined in different ways to form PV-T system [Ramos et al, 2017]:

- unglazed without thermal insulation;
- unglazed, without thermal insulation, heat exchanger as a separate unit under PV module;
- unglazed with thermal insulation;
- glazed PV cells are placed on the absorber;

- glazed PV cells are placed right under the transparent insulation/glass pane;
- PV-T solar collectors with concentrators.

Despite the potential benefits, PV-T systems are yet to make a breakthrough in the heating and cooling market. Only a small number of manufacturers are producing them and the market remains small. One of reasons for this is high CAPEX. In the UK the capital cost of PV-T systems is up to USD 750/m^2, twice the cost of an equivalent PV system [UK Gov., 2016]. The main cost component of the system is the hybrid collector, thus its cost should be lowered to make such systems cost competitive.

Hybrid PV-T systems face competition from other hybrid technologies, such as PV modules combined with a heat pump which have some significant advantages on PV-T systems.

3 R&D OVERVIEW

R&D initiatives related to solar heating and cooling technology in Europe are presently limited. The previous version of this report [Bloem, 2016] identified only 3 large scale FP7 and 9 IEE projects related with R&D in solar heating and cooling. These projects were executed in the period 2005-2017. The total budget of these 12 projects was EUR 22.2 million, with an EU contribution of EUR 15.4 million.

The analysis of current H2020 projects identified 8 large scale projects involving R&D in solar heating and cooling. Their cumulative budget is EUR 26.5 million, with a EUR 22.9 million EU contribution. A number of small projects (with EU financial contribution up to EUR 50 000), were not considered here. This report also omits projects that are only partially related with solar heating and cooling, such as those dealing with heat storage and cogeneration involving solar energy; instead these are analysed in a separate LCEO report on technology synergies for clean energy supply.

174 different research organizations, companies, associations, agencies and governmental institutions have taken part in the different solar heating and cooling related IEE, FP7 and H2020 projects. There were 99 different participants in IEE and FP7 projects and there are 88 participants in H2020 projects. Some participants took part in a number of projects. Some participants of FP7 and IEE projects are taking part in H2020 projects as well.

Table 1 shows the organisations that feature most prominently in EU funded solar heating and cooling projects. Organisations from 30 countries have participated: 22 from EU Member States and 8 from non-EU countries. At least 14 organisations participated in projects in two or more EU programmes, showing their sustained interest in this research topic.

The most active countries (see Table 2) are Germany and Spain. This is no surprise since Eurostat data (Eurostat, 2016) shows that approximately 45 % of directly used solar thermal energy in the EU is generated in these two countries. In fact, Spain accounts for almost 58 % of all solar thermal energy used in EU, but the largest part is used for electricity generation only.

Table 1. Most active organizations involved in EU funded solar heating and cooling projects

Organisation	Country	Number of projects
PlanEnergi	DK	6
Fraunhofer	DE	5
AEE Institut fur nachhaltige technologien	AT	5
Ambiente Italia srl	IT	5
Commisariat a l'energie atomique et aux energies alternatives	FR	4
University of Ljubljana	SI	4
Universität Stuttgart	DE	4
Steinbeis Forschungs- und Entwicklungsz. GmbH	DE	4
EC BREC Instytut Energetyki Odnawialnej Sp. z.o.o.	PL	3
CITYPLAN spol. s.r.o.	CZ	3
S.O.L.I.D. Company for Installation of Solar and Design	AT	3
Euroheat & Power	BE	3
TECSOL	FR	3
CIT Energy Management AB	SE	3
Centre for Renewable Energy Sources	EL	3

Table 2. Participation in solar heating and cooling R&D projects by country

Country	Participants in FP7, IEE and H2020 projects
Germany	24
Spain	22
Italy	16
France	17
Austria	13
Netherlands	9
Portugal	7
United Kingdom	7

3.1 Research Focus and Topics

The SET-Plan Integrated Roadmap indicated an array of specific actions divided into 3 main research programmes for the increased uptake of solar heating and cooling:

1. Advanced Research;
2. Industrial Research and Development;
3. Innovation and Market Uptake.

A review of the H2020 projects' alignment with the SET-Plan Integrated Roadmap indicates that the projects try to address the following actions:

- *Industrial research and demonstration*
  - development of innovative solar compact hybrid systems and innovative solutions (4 projects);
  - investigation of refurbishment options in existing buildings (2 projects);
  - study of large scale solar collector arrays for industrial processes (2 projects);
- *Innovation and market uptake*
  - development of new business models (1 project).

Some reviewed projects addressed issues not mentioned in the SET-Plan Integrated Roadmap. These include development of:

- equipment for the utilisation of high temperature solar heat in industrial processes (1 project);
- policies and market support measures for the implementation of solar district heating and cooling (2 projects).

Only a limited number of projects deal with technological improvements. This reflects the fact that this is a mature technology, leaving very little scope for break-through solutions.

3.2 H2020 Projects

Table 3 shows the main solar heating and cooling projects under the framework of H2020 and in Table 4 these are categorised according to the research and innovation actions in the SET-Plan Integrated Roadmap [SET-Plan, 2014] since, contrary to some other renewable technologies under the SET-Plan (under the update of the SET-Plan in 2016 this technology is addressed as part of xxxx, without an individual implementation plan).

Table 3. Horizon 2020 projects on solar heating and cooling (TRL targets as indicated by project executors themselves) (source: CORDIS)

Project acronym	Project start	Planned project end	Total budget, k€	EU funding, k€	Application area	Target TRL
SOLPART	01/01/16	31/12/19	4 558	4 366	Industry	**4-5**
CHESS-Setup	01/06/16	31/05/19	3 703	3 364	Buildings	**7**
SDHp2m	01/01/16	31/12/18	2 087	1 919	Policies	**N/A**
Re-Deploy	01/02/16	31/01/19	2 893	2 025	Industry	**9**
Envision	01/10/17	31/03/22	5 974	4 900	Buildings	**7-8**
CoolHeating	01/01/16	31/12/18	1 644	1 644	Policies	**N/A**
INSHIP	01/01/17	31/12/20	2 858	2 498	Industry	**2-5**
ZEOSOL	**01/06/17**	**30/11/19**	**2 741**	**2 167**	**Buildings**	**9**

Table 4. Research topics of the Horizon 2020 projects on solar heating and cooling (source: CORDIS)

Research topics	SOL PART	Chess-Setup	SDHp2m	Re-Deploy	En-vision	Cool Heat-ing	INSHIP	ZEO-SOL
Industrial research and demonstration								
Develop innovative solar compact hybrid systems and innovative solutions for new-built houses		x			x		x	x
Investigate refurbishment options in existing buildings					x			x
Study large scale solar collector arrays for industrial processes	x						x	
Innovation and market uptake								
Develop new business models and standardisation of components in buildings				x				
Other (not in SET-Plan)								
Policies and market support for the implementation of solar DH and DC, public information			x			x		

3.3 International Research and Developments

3.3.1 International Energy Agency

The IEA-SHC Technology Collaboration Programme currently runs a number of research projects (tasks), related with solar heating and cooling, among others:

Task 60: Application of PV-T Collectors and New Solutions in HVAC Systems;

Task 57: Solar Standards and Certification;

Task 56: Building Integrated Solar Envelope Systems for HVAC and Lighting;

Task 55: Towards the Integration of Large SHC Systems in District Heating and Cooling Networks;

Task 53: New Generation Solar Cooling and Heating Systems (PV or Solar Thermally Driven Systems).

Many of the research topics treated by IEA-SHC are also dealt with in EU funded H2020 research projects analysed in this report. The common topics include analysis of hybrid solar PV-T systems, integration of solar heat into district heating and cooling networks, development of building envelope renovation elements containing solar energy gathering equipment and so on. The IEA-TCP also covers important regulatory subjects such as Task 57, that aims to develop, improve and promote ISO standards on test procedures and requirements for solar thermal products, and to harmonize at international level certification schemes in order to increase in general the level of quality and at the same time avoid the need for re-testing and re-inspection.

3.3.2 Australia

The Australian Renewable Energy Agency (ARENA) provides funding for a large number of solar energy related research projects. However, most of these projects are concerned with solar PV and solar thermal electricity technologies. Projects dealing only with solar heating and cooling are limited in number.

In 2016 ARENA dedicated AUD 4.49 million (EUR 2.9 million) to a project on the integration of concentrating solar thermal technologies into the alumina refining process. The aim of the project is to develop the technologies and process knowledge to enable the integration of low and high temperature concentrated solar thermal (CST) into the existing industrial alumina refining process as well as solar reforming of natural gas.

4 IMPACT ASSESSMENT OF H2020 PROJECTS

This section analyses the contribution of the most significant H2020 projects in this area (see Table 4). All the identified projects are ongoing at the time of writing and no conclusions can be made about their results as yet. Hence their potential impact is discussed based on the goals stated in the project documentation.

4.1 Industrial research and innovation

The majority of solar heating and cooling related H2020 projects deal with different aspects of industrial research and innovation.

Industrial research and innovation
Areas of activity (according to SET-Plan Integrated Roadmap): • Prototype development and demonstration of SCOHYS for single and multifamily homes • Demonstration of new built single family SAH • Prototype development and demonstration of new built multifamily SAH • Prototype development and demonstration of refurbishment solutions for existing buildings to SAH • Technical development and demonstration of cost optimal SHIP solutions for all relevant industrial processes
Target TRL: 5-9
Related H2020 projects
Envison, SOLPART, Chess-Setup, INSHIP, ZEOSOL

ENVISION, having 13 partners, aims to research and develop different building elements which would enable energy harvesting from solar irradiated surfaces of the buildings. Research activities target three building elements. Two activities address solar heat collection:

1. *Heat collecting non-transparent aesthetic prefab façade element*. It is intended that the element will harvest more than 1.5 GJ/m²a, by developing thermally harvesting near infrared coatings (with more than 50 % efficiency) for a wide range of popular façade colours. Target TRL for this element is 8.
2. *Ventilated window collecting heat*. The ventilated glass solution is intended to capture more than 0.8 GJ/m²a of heat, by absorbing the solar irradiation (>30 % efficiency), to be collected by air via heat-exchangers. Target TRL for this element is 7.

The project intends that these elements would be used during renovation of the buildings to contribute towards making them near-zero-energy building (NZEB) compliant. Since renovation duration and costs are identified as the critical aspects, the final solution is intended to be available as prefabricated modular façade elements.

SOLPART (11 partners) aims to develop a high temperature (950 °C) continuous operation solar process suitable for particle treatment in energy intensive industries. The system would include solar reactor, transport of high temperature solid materials and high temperature heat storage.

The aim of SOLPART project is to develop the process at a pilot scale with TRL target of 4-5 with the demonstration of the main building blocks, solar reactor and high temperature storage and operation of a pilot over a relevant period of time in a continuous mode.

CHESS-SETUP, having 11 partners, has the goal of designing and promoting reliable, efficient and cost-effective heating and hot water preparation system for buildings. The proposed system would be based on the combination of solar collectors, seasonal heat storage and heat pumps. Hybrid photovoltaic and solar thermal (PV-T) panels are intended to be used.

Integration of other renewable energy sources, such as biomass and waste heat, will also be investigated in order to make the systems to be suitable to use under diverse climate conditions. The target TRL of the project is 7. The suitability of the proposal will be tested using three pilot systems in Spain and UK.

INSHIP, consisting of 27 partners, aims to tackle specific research topics related with the utilisation of solar heat for industrial processes (SHIP). The research activities aim to develop technical solutions at TRL 2-5 and include, among other:

1. integration of solar heat at process level, durability and reliability of solar collectors under industrial environment conditions
2. design of more compact solar collectors for the utilisation of building facades;
3. design of point-focus optical systems adapted to reactor/kiln shaped receivers;
4. design of specific industrial processes in the Energy Intensive (EI) industrial sectors aiming an integration of solar heat at process level;
5. use of centralized heat storage systems as regulator element to the electricity grid.

The project will tackle these and other tasks by cooperation between EU research institutions, alignment of different solar heat related national research and funding programs, acceleration of knowledge transfer to the European industry and other activities.

ZEOSOL, having 5 partners, has a number of goals. It aims at developing hybrid heating and cooling systems, consisting of solar vacuum tube collectors, heat storage, adsorption chiller and a heat pump. The aim is to lower the cost of such system to EUR 2 000/kW in order to make it competitive on the market. The target TRL of the final system is 9, meaning that it will be certified and tested under real environmental conditions during the pilot plant stage.

The main research activities of the project are aimed at the improvements of the adsorption chiller, which will operate together with the improved solar collector unit.

An additional goal of the project is to develop evacuated tube collectors based on the commercial product of one of project partners. The collector would be suitable to be combined with the thermal chiller. Area specific performance is intended to be increased by decreasing the tube distance and installing more tubes per m^2. Thermal insulation of solar collectors can significantly reduce heat losses. All these measures are expected to increase annual yield of solar energy by 35 % while manufacturing and installation costs are expected to decrease by 44 % to EUR 250/m^2. The target TRL for the solar thermal collectors at the end of the project is 9.

4.2 Innovation and market uptake

Only one project specifically deals with the issues of innovation and market uptake.

Innovation and market uptake
Areas of activity (according to SET-Plan Integrated Roadmap): • Market uptake of innovative SCOHYS for single and multifamily homes • Market uptake of new built single family SAH • Market uptake of solar heat for industrial processes (SHIP)
Target TRL: 9
Related H2020 projects
RE-DEPLOY

RE-DEPLOY has only one participant. The essence of the project is to create and develop new business model involving solar heating systems. The ambition is to develop cost competitive re-deployable (i.e. ready to use and easy to install) solar thermal systems of at least 1 MWth capacity. Such systems could be used to sell heat (as opposed to equipment) to customers. The solar thermal system would be offered to the customers under minimal initial commitment (only 3 years). Afterwards, the customer would be able to continue to buy the energy or the system would be dismantled and re-deployed at a different user's site.

The ambition is to demonstrate the proposed business concept by implementing it at industrial sites in target geographic segments - two pilot installations of approx. 2 500 m² of net collecting surface (i.e. more than 1 MWth) each.

The project aims to reduce costs to EUR 250/m² which is at least 30 % less than the 2017 price target of EUR 400/m² set by the Renewable Heating and Cooling European Technology Platform (RHCETP) for solar concentrating systems for industrial process heat.

4.3 Policies and market support measures

Two projects address the improvement of solar district heating and cooling related policies, regulatory and financing frameworks.

Development of favourable policies and market support measures
Areas of activity: • Addressing market uptake challenges for a wider use of large scale solar thermal plants • Support the implementation of small modular renewable district heating and cooling grids
Target TRL: -
Related H2020 projects
SDHp2m, COOLHEATING

SDHp2m, which stands for Solar District Heating (SDH) and actions from policy to market, has 15 partners. It is the continuation of previous IEE projects SDHTAKE-OFF and SDHplus (see [Bloem, 2016]) with many recurring project partners. Seven of the partners participated in all three projects.

SDHp2m aims to address market uptake challenges for a wider use of large-scale solar thermal systems combined with other RES in DHC systems.

The approach of the project is to develop, improve and implement in 9 participating European regions (3 focus and 6 follower regions) advanced policies and support measures for SDH. The project activities aim at mobilization of investments in SDH and a significant market rollout due to an improved policy, regulation and financing framework backed with efficient market support and capacity building measures.

COOLHEATING, having 11 partners, has the objective to support the implementation of small modular renewable district heating and cooling (DHC) grids for communities in South-Eastern Europe. This would be achieved through knowledge transfer and mutual activities of partners in countries having renewable district heating systems (Austria, Denmark, Germany) and in countries where such systems are rare or non-existent (Croatia, Slovenia, Macedonia, Serbia, Bosnia-Herzegovina). Major activities of the project, besides techno-economic assessments, include measures to stimulate the interest of communities and citizens in renewable DHC systems as well as the capacity building on financing and business models.

The specific objectives of the project include initiation of small modular DHC grids up to the investment stage and improvement of national policies.

5 TECHNOLOGY DEVELOPMENT OUTLOOK

5.1 Technology development trends and needs

The current developments are mainly concerned with the integration with other renewable technologies to form so-called hybrid systems (combining with solar PV modules, heat pumps, biomass boilers, etc.), integration of solar heat into other heat supply systems, such as district heating and cooling networks or the use of high temperature solar heat in industrial processes. Another current development is the integration of solar thermal technologies in the building envelope, such as windows and facades, to maximise solar yield and to provide ready to use solutions for the renovation of the current EU building stock.

The key issue for solar thermal technologies is the reduction of CAPEX for solar heating and cooling installations. Proper economic analysis of solar thermal systems is a complex issue affected by the integration in more conventional heating (and cooling) systems. A life cycle cost (LCC) evaluation, e.g. evaluation of all costs for energy delivery by the system becomes complicated due to different costs for electricity, gas or heating oil in the EU-28 Member States as well as from the solar collector application. The life cycle savings (LCS) for a solar system is usually compared to that of a conventional system. In general, solar energy processes are characterized by high initial costs (CAPEX) and low operating costs (OPEX).

The SET-Plan Integrated Roadmap identified a number of issues that solar heating and cooling should overcome in order to increase its market share and make a more significant contribution towards the decarbonisation of the energy system:

1. Increase production value chain performance/cost competitiveness:
   a. Reduce the solar heat costs by 50 % by 2020 through highly integrated compact hybrid heating systems;
   b. Reduce the solar heat costs by 50 % for industrial processes to 3-6 EURct/kWh for low temperature applications up to 100 °C and 4-7 EURct/kWh for medium temperature applications up to 250 °C.
2. Develop higher system integration (smart interfaces, new capabilities of equipment, new or improved services to system, forecast):
   a. develop compact heating systems integrating solar and backup heaters;
   b. develop improved control and monitoring concepts by using new ICT technologies to increase performance and reliability and optimized cooperation of solar, backup heater and building components;
   c. develop standardized hydraulic and electrical inter-connections between all solar thermal and HVAC-systems of the building.
3. Develop non technological aspects (market framework, business models, spatial planning, standards, financing, skills and capacities):
   a. provide transparency and comparability on the system yield of solar heating and cooling systems;
   b. develop new financing and business models for SHC projects and provide the legal framework.
4. Solve societal issues (environment impact, safety, health, social acceptance):
   a. simplify the handling and increase the user-friendliness of SHC systems;
   b. improve the architectural design of solar collectors to increase the acceptance of such installations.

5.2 Targets and KPIs

All Member States reported in their NREAPS the national target for renewable energy production by 2020, as well as planning values for solar thermal energy. These Member State planning values [European Commission, 2017], [Jaeger-Waldau et al, 2012] have a huge spread and are not always correlated to the level of solar irradiation, but more to other factors such as the price of alternative energy sources or availability of governmental incentives.

Nonetheless, the annual growth of installed solar thermal collectors in EU over the years has been declining. The contraction of the market began in 2008 and since then additions have contracted by an annual average of 6.9 %. In 2008 (peak year) 4.6 million m² of solar collectors were added in EU. The total surface area added in EU in 2016 was 2.7 million m² (corresponds to approx. 1.8 GWth) (EurOBserv'ER, 2017).

There are a number of reasons for the contraction. One of them is the major financial and economic crisis that started in 2008 and whose consequences are still felt. Other reasons are low fossil fuel prices and vigorous competition from other renewable technologies, especially solar PV with which solar thermal must compete for available space.

This means that the NREAP 2020 target of 75 TWh of solar thermal energy most likely will not be reached. The 34.4 GW_{th} (Solar Heat Europe, 2017) in operation by the end of 2015 generated an estimated 23.6 TWh_{th} of solar thermal energy, while contributing to a saving of 2.75 Mt CO_2.

As it can be seen in Figure 5, the current market trend is far behind the expected contribution of solar thermal to the renewable energy target for 2020.

In 2014, under the framework of the SET-Plan Integrated Roadmap, the stakeholders of the solar heating and cooling technology put together a number of key actions that should be achieved by the sector in the short to medium term (2020 and beyond), presented in Table 5.

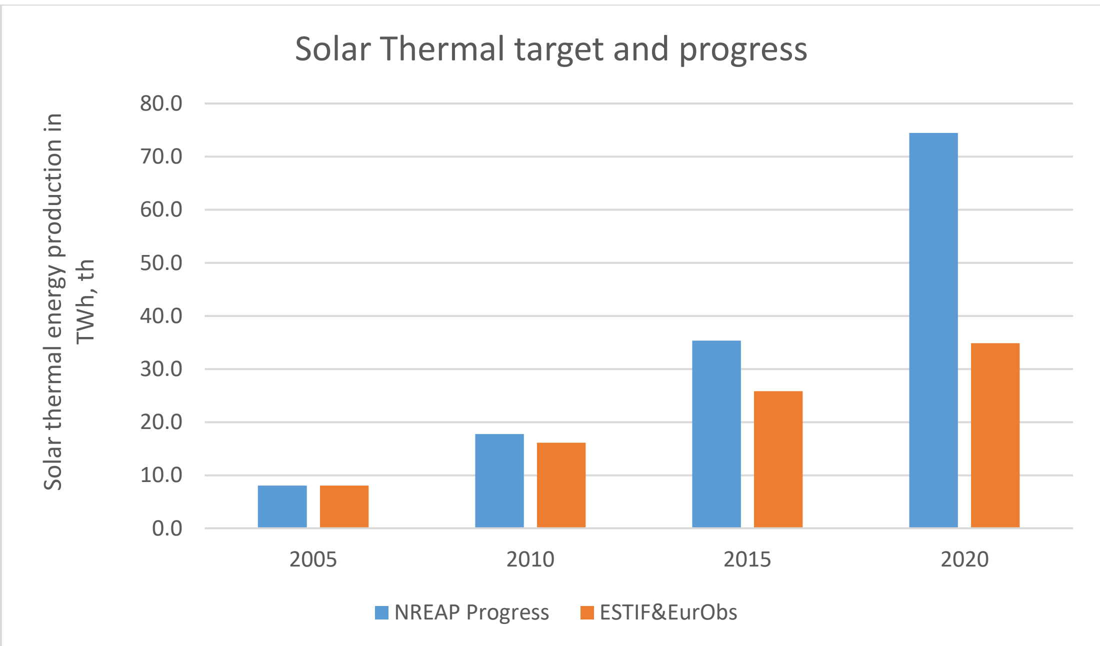

Figure 5. Expected solar thermal market development according to NREAP planning & other projections

Table 5. Proposed actions and KPIs for solar heating and cooling technology as identified by stakeholders under SET-Plan Integrated Roadmap

Proposed Action	Description	KPI
Advanced research 1	Development of solar compact hybrid system (SCOHYS) for single family and multifamily homes	Prototype installations with solar heat costs reduced by 35 % in comparison to 2013, reaching fossil fuel parity in Southern Europe (< 10 EURct/kWh)
Advanced research 2	Applied research and prototypes on new built single family Single Active House (SAH)	SAH with 60 % solar fraction to be ready for the market as a standardized solution
Advanced research 3	Applied research and technical development of the next generation of medium temperature collectors (100 °C to 250 °C)	The solar heat costs to be reduced to 3-6 EURct/kWh for low temperature applications (<100 °C) and 4-7 EURct/kWh for medium temperature applications (<250 °C)
Industrial research and demonstration 1	Prototype development and demonstration of SCOHYS for single and multifamily homes	SCOHYS with solar heat costs reduced by 50 % in comparison to 2013 (reaching the fossil fuel parity target for Central Europe)
Industrial research and demonstration 2	Demonstration of new built single family SAH	Ready for the market standardized solution
Industrial research and demonstration 3	Prototype development and demonstration of new built multifamily SAH	Solution to provide solar heat at costs comparable to today's combi systems in central Europe (between 15 and 20 EURct/kWh).
Industrial research and demonstration 4	Prototype development and demonstration of refurbishment solutions for existing buildings to SAH	Solution to provide solar heat at costs comparable to today's combi systems in central Europe (between 15 and 20 EURct/kWh).
Industrial research and demonstration 5	Technical development and demonstration of cost optimal SHIP solutions for all relevant industrial processes	Investment costs reduced to 350 EUR/m² for low temperature systems with storage and 400 EUR/m² for medium temperature systems without storage
Innovation and market uptake 1	Market uptake of innovative SCOHYS for single and multifamily homes	New and improved business models
Innovation and market uptake 2	Market uptake of new built single family SAH	Certification scheme for all types of NZEB including SAH
Innovation and market uptake 3	Market uptake of solar heat for industrial processes (SHIP)	Integration of SHIP in industry energy audits

5.3 Technology barriers to large scale deployment

Solar thermal is often considered as a technology that avoids the use of other energy technologies and therefore often lacks data to prove its important contribution. Compared to solar electricity (PV) for which electricity production is measured and therefore can be directly linked to a monetary value, solar thermal energy for domestic applications is produced and used without a direct financial evaluation and is often not taken into account in evaluation models.

The barriers this technology faces are for the most part non-technological but there are also technical barriers to its large scale deployment. For instance, [Ossenbrink et al, 2012] noted the following barriers:

- low gas prices;
- difficult access to finance for consumers;
- slow-moving construction sector;
- less public support schemes for solar thermal and competition from other renewable energy sources that also are eligible for incentives and offer cheaper installation costs.

At technological level improved hybrid systems such as gas-solar or solar PV-solar thermal heating for sanitary hot water could help further progress in market penetration. Similarly to some other renewable technologies, the reliable supply of solar thermal energy while maximising the use of the solar resources requires thermal energy storage [Ramos et al, 2017]. The main challenge related with heat storage is that it requires an unoccupied area that may not be available in small houses. However, with proper heat storage solar energy can be used during different times of the day thus increasing utilisation of the system. Heat storage and distribution infrastructures such as district heating and cooling networks maximise the use of available solar heat. Thus integration of solar thermal into such systems should be viewed as a very important task.

Solar thermal installations often face the so-called 'landlord dilemma', whereby the person paying for the investment in the solar unit does not benefit from the savings [Ramos et al, 2017]. This problem arises because of the large number of rented houses, combined with the high initial costs that landlords need to pay for a solar-thermal system. In the case of solar PV the largest share of investment is in a PV module itself which can be later moved to the other location. In case of solar thermal, the largest portion of the capital investment is for planning and labour while installing the system.

Another factor is the strong variability in gas and electricity prices across the EU, which strongly affects the local competitiveness of solar thermal technology. For instance the electricity prices might make it more profitable to invest in the solar heaters in Denmark than it would be in Greece, which has much higher annual solar irradiation.

Compared to other solar energy technologies, e.g. photovoltaics and solar thermal electricity, contracts can be made for delivery of electrical energy and for the appreciation time of the system. Solar thermal energy is produced locally and consumed locally and hence remains out of the direct monitoring of energy providers. An assessment of the solar thermal heat contribution to the energy consumption in the building sector would be needed in order to stimulate the market.

A solar collector can be installed in different climates and different applications. The Ecodesign Directive requires an energy label for the solar collector. However, this does not necessarily give an indication of the produced (thermal) energy. An agreement on the solar yield for solar collectors should clarify the data that can be used by the market and modellers.

5.4 Solar heating and cooling in energy system models

In general, energy system studies do not address the deployment of solar heating and cooling technologies in detail, compared to other low carbon energy technologies [Tsiropoulos et al, 2018]. This also reflects the inherent complexity of the foreseen applications, which include the following options

- Scale: residential, commercial
- End use: sanitary hot water, heating/cooling system, or both
- Hybridisation: possible combinations with gas, heating oil, biomass, heat pumps, electrical resistance heaters

The LCEO project uses the JRC-EU-TIMES model to analyse the EU energy system [Nijs et al, 2018]. However the results for the solar heating and cooling were deemed to be less accurate and contain a lower level of detail compared to other heating and cooling technologies, and therefore are not reported here.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

Solar thermal energy has the potential to be a major source of heating and cooling in a decarbonised energy sector of Europe. However, in order to unlock its potential and to give the solar thermal industry a boost, focussed and coordinated research and innovation activities are needed.

The EU funded H2020 projects are performing important R&D actions which are vital for strengthening the solar thermal heating and cooling competitiveness and wider acceptance and implementation of this technology.

The analysis of H2020 projects identified 8 large scale projects related with R&D in solar heating and cooling. The total cost of these projects is EUR 26.5 million, of which EUR 22.9 million is the EU financial contribution.

The majority of solar heating and cooling related H2020 projects are dealing with different aspects of industrial research and innovation. The main R&I actions are related to:

- development of hybrid PVT heating and cooling systems;
- development of solutions for building renovation integrating solar heat collection;
- developing solutions for integration of solar heat in industrial processes.

Another group of H2020 projects is concerned with providing impetus to the improvement of solar district heating and cooling related policies, regulatory and financing frameworks. These aim to address market uptake challenges for a wider use of large and small scale solar thermal systems combined with other RES in district heating and cooling systems.

6.2 Recommendations for future R&D priorities

Solar thermal energy needs to be dealt with in a more holistic way. Energy system models are not coping well with the potential of this resource. In addition, more R&D is needed on passive solar technologies that are integrated in buildings and building elements, like windows and glass facades.

Solar thermal technologies can be used to the cover energy needs of different consumers in different sectors. Although the challenges faced are similar, there are also peculiarities for each of them that need to be addressed.

6.2.1 Solar domestic hot water and space heating systems

Solar thermal systems are mainly used in residential buildings (usually single family homes) for domestic hot water and space heating. The main challenge is to lower the cost of solar heating systems to make it more competitive with other renewable energy technologies, especially solar PV modules. Costs per solar heat unit could be significantly decreased through improved system performance and lower component as well as installation costs [Stryi-Hipp et al, 2012]. R&D needs to focus on development of innovative construction concepts, new materials and improved production methods. Solar thermal systems should also be improved through simpler design and optimised control.

Synergies with other renewable technologies, especially solar PV, should be further explored. Currently, the complexity of combining solar thermal with another heat source is confusing for customers and installers [Stryi-Hipp et al, 2012]. The development of easy to install and operate PV-T units would make solar thermal energy a more attractive and cost-effective solution. There is a need to identify the most energy and cost efficient hybrid system designs, incorporating other RES, such as biomass boilers and heat pumps.

Another area where solar thermal can play a more significant role is the renovation of the existing housing stock. Solar thermal collectors integrated in façade systems could become a cost-effective and clean heat supply option and increase the solar fraction to 60 % [SET-Plan, 2014]. R&D is needed to develop solar thermal collectors as an integral element of the façade and to meet the challenges of combining the solar collector with other functional systems such as insulation, ventilation and heat distribution [Stryi-Hipp et al, 2012].

6.2.2 Industrial and large scale solar heating applications

Solar thermal technologies have a significant potential to be used in industrial and service sectors. Solar thermal systems could also play a more prominent role as a heat source for district heating and cooling systems, where heat is needed whole year round.

In order to achieve these goals, R&D is needed to develop advanced district heating systems incorporating a combination of renewable heat sources such as solar thermal, heat pumps, biomass (boilers and CHP plants) and heat storage technologies.

R&D is also needed to identify and optimize relevant industrial processes to make them more suitable for solar thermal systems, e.g. through adaptation of processes and machinery for solar input. Novel integration schemes for solar heat should be developed on process and supply level of industrial plants and solar thermal system designs optimized accordingly [Stryi-Hipp et al, 2012].

To make solar heating for industrial processes a viable solution, R&D on high-temperature solar collectors is needed. High temperature-resistant materials should be researched to make the development of new collector designs possible. Large scale solar collector arrays should be optimised for uniform flow distribution and low pumping power [SET-Plan, 2014].

6.2.3 Solar cooling systems

Currently most of cooling is provided using electricity. However, this causes significant problems during peak space cooling load periods when the electricity grid may become overloaded. Solar thermal technology is an attractive alternative, especially taking into account the coincidence in periods of solar energy availability and space cooling demand.

Targeted R&D is needed to make solar cooling more cost competitive R&D activities should be directed at both improvements in solar cooling system components and improvements of cost and performance of solar cooling systems. Solar cooling systems must be optimized for the use in industry and DHC networks.

7 REFERENCES

Bloem, H. Solar Thermal Heating and Cooling Technology Development Report. Low Carbon Energy Observatory Deliverable D 2.1.4, 2016. JRC 1050755

ESTIF (2016). Solar Thermal Markets in Europe; Trends and Market Statistics 2015. European Solar Thermal Industry Federation

EurObserv'ER (2017) The State of Renewable Energies in Europe 2016. URL: https://www.eurobserv-er.org/16th-annual-overview-barometer/

European Commission (2015) Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation. Brussels, 15.9.2015 C(2015) 6317 final.

European Commission (2016). Commission staff working document part 2/2 to the EU Strategy for Heating and Cooling - SWD(2016) 24 final.

European Commission (2017) Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Renewable Energy Progress Report. Brussels, 1.2.2017 COM 92017) 57 final.

European Parliament (2009) DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Eurostat (2016) Primary production of renewable energy by type. http://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=ten00081&language=en

IEA. (2011). Solar Energy Perspectives. Paris: International Energy Agency.

IEA (2012) Technology roadmap. Solar heating and cooling. International Energy Agency, 2012. URL: https://www.iea.org/publications/freepublications/publication/technology-roadmap-solar-heating-and-cooling.html

IRENA (2015) Quality Infrastructure for Renewable Energy Technologies – Solar Water Heaters, 2015. www.irena.org

Ivancic et al, (2014) Ivancic, A., Mugnier D., Stryi-Hipp G., Weiss W. Solar Heating and Cooling Technology Roadmap. European Technology Platform on Renewable heating and Cooling. Brussels, RHC platform, 2014.

Jaeger-Waldau et al, (2012) Renewable Energy Snapshots 2012. Solar Heat. Page 23-28. EUR 25756 EN

Nielsen J.E. (2011) Converting Installed Solar Collector Area & Power Capacity into Estimated Annual Solar Collector Energy Output. IEA SHC, 2011.

Nijs et al, (2018), Deployment Scenarios for Low Carbon Energy Technologies, EUR 29496 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-98184-5, doi:10.2760/249336, JRC112915

Ossenbrink et al, (2012) Ossenbrink, A. Jäger-Waldau, N. Taylor. Economic evaluation for energy system supply. New Opportunities for PV Systems. H. ESPVC Hamburg 2012.

Ramos et al, (2017) Ramos, A., Guarracino, I., Mellor, A., Alonso-álvarez, D., Childs, P., Ekins-Daukes, N. J., Markides, C. N. Solar-Thermal and Hybrid Photovoltaic-Thermal Systems for Renewable Heating. Grantham Institute, Briefing paper No 22. Imperial College London, 2017.

Sawin et al, (2016) Sawin J. L. (lead author), Renewables 2016: Global status report. REN21 (Renewable Energy Policy network for the 21st Century), 2016.

SET-Plan (2014) Towards Integrated Roadmap: Research & Innovation Challenges and Needs of the EU Energy System. Annex I: research and innovation actions. JRC93060. Brussels, 2014. URL: https://setis.ec.europa.eu/set-plan-process/integrated-roadmap-and-action-plan

Solar Heat Europe (2017) Solar heat markets in Europe. Trends and market statistics 2006. Solar Heat Europe, November 2017.

Stryi-Hipp et al, (2012) Stryi-Hipp G., Weiss W., Mugnier D., Dias P. et al, Strategic research priorities for solar thermal technology. European Technology Platform on Renewable Heating and Cooling, 2012.

Thirugnanasambandam M. et al, (2010) A review of solar thermal technologies. In Renewable and Sustainable Energy Reviews, page 312-322.

Treberspurg M., Djalili M., Staller H. New technical solutions for energy efficient buildings. State of the art report. Solar heating & cooling. SCI-Network, 2011.

Tsiropoulos I, Tarvydas D, Georgakaki A, Zucker A, Review of Global Energy Scenarios - Low Carbon Energy Observatory Deliverable D 4.3, European Commission, Petten, 2017, JRC107767

UK Gov. (2016) Evidence Gathering – Low Carbon Heating Technologies. Hybrid Solar Photovoltaic Thermal Panels. UK Government, Department for Business, Energy and Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545246/Solar_PVT_FINAL__1_.pdf

Weiss et al, (2017) Weiss W., Spork-Dur M., Mathner F. Solar heat worldwide. Global market development and trends in 2016 / Detailed market figures 2015. IEA Solar heating and cooling programme, May 2017.

KJ-BK-19-009-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/706387

ISBN 978-92-76-12539-6